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THE RELATION BETWEEN BODY SIZE AND ORGAN SIZE IN PLANTS[1]

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IN the animal kingdom, particularly among its more highly specialized members where the primitive condition of indefinite multiplication of similar organs has given way to a high degree of differentiation, there is necessarily a close correlation between the size of a given organ and the size of the organism of which it forms a part. A particularly large individual will tend to have proportionally large bodily structures, and *vice versa*. In the case of the higher plants, however, with their multiplication of similar organs and their notably lower degree of organization and individuation, an interdependence between body size and organ size is certainly much less obvious. We need only to call to mind the general similarity between leaves or fruits from small and from large trees to realize that in these larger, woody plants, at least, there is no very striking correlation between the size of the body and the size of its parts. In certain herbaceous forms, however, evidence has from time to time been brought forward that such a correlation does in fact exist and that the largest plants (whether measured by dry weight, height, number of stalks or yield) are those which bear the largest fruits and seeds. The importance of such a conclusion on the theory and practice of seed selection is evident; and the

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question is also of considerable theoretical significance in that it bears directly on the perplexing problems of individuality and organization. The aim of the present paper is to contribute to the solution of this problem by undertaking a careful analysis and interpretation of size relations in a series of bean plants.

HISTORICAL

The problem, at least in certain of its aspects, has received attention at the hands of workers in several fields. Students of the cereal grains, in particular, have been interested in determining whether those plants which are large in the sense of having tall or many stems or a high yield are plants which produce large heads and seeds. This question is of importance in seed selection, since if high yield and large seed size are correlated, it will be comparatively easy to pick out from a mixture those seeds which have been produced by high-yielding plants. Scattered papers on other crops than the cereals also provide facts of interest.

Most work has been done with the small grains, particularly wheat and oats. Lyon (11) in 1906, although not using biometrical methods, observed that in wheat the weight of the average kernel is not correlated with the number of kernels per head or with the number of kernels per plant. He states that the highest yielding plants have medium-sized spikes and medium-sized kernels.

Waldron (20) in 1910, working with oats, reported substantial *negative* correlations (— .4 to — .6 approximately) between average weight of seed per plant and (1) number of seeds, (2) length of head, and (3) length of culm, thus indicating that the larger the plant, the smaller were its seeds.

Results at variance with those of Waldron were recorded in 1911 by Love (9), Roberts (14) and Myers (12), working with wheat, and by Leighty (7), with oats.

These authors generally agree that there is a positive, though small, correlation, usually of about the magnitude of .2 to .4, between the size of the plant, as measured by height or by yield, and the average weight of the seeds it produces. Larger plants also tend rather consistently to have larger heads.

In two extensive memoirs on oats in 1914 Love and Leighty (10) and Leighty (8) presented an abundance of data on this problem. In the former paper the authors find positive and fairly large correlations between the size of the plant, as measured by yield, and the size of each head, as measured by its individual yield or by the number of spikelets or number of kernels which it produces. The average weight of kernel per plant is not very consistently correlated with any character representative of plant size, however, although most of the correlation coefficients are positive and many are, in certain seasons, significantly large. In the second paper the author, working with another variety, finds consistent, positive and significant correlations between plant height and average weight of kernels. He points out that the degree of correlation in all characters studied increases considerably as the plants are reduced in size through crowding.

Arny and Garber (1) in 1918 found that, in wheat, plant height and plant yield are positively correlated with spike length; and that average kernel weight is positively and consistently correlated with yield (total kernel weight) and with number of kernels. The authors mention unpublished work of Atkinson and Hutchinson who found substantially the same results.

With corn, the reports are somewhat conflicting. Ewing (2) found a positive but small correlation between yield and leaf length and breadth. Hutcheson and Wolfe (6) found a significant correlation between yield and both length and circumference of ear. Olson, Bull and Hayes (13) and others, however, find no significant correlation between yield and any other character studied.

With apples, Shaw (15, 16, 18) and Stewart (19) have pointed out that there is little relation between the yield of fruit on a tree and the average size of the fruit except in very heavy yields, when fruit size decreases. Small, young trees may have slightly larger fruits than large, old trees. Many investigators maintain, however, that under most conditions thinning will increase the size of the fruit and thus imply that there is usually a negative correlation between yield and fruit size.

In tobacco, Hayes (5) found that there is probably no significant correlation between number of leaves and average leaf area.

In beans, Harris (3, 4) found a small positive correlation between number of pods per plant and (1) number of ovules per pod and (2) average weight of seed per plant, the higher yielding plants thus having somewhat larger pods and somewhat heavier seeds.

In peas, Shaw (17) found that a positive but small correlation exists between length of vine and average weight of seed produced, and that this correlation is much greater in small plants than in large ones.

The total evidence is therefore conflicting. A majority of the workers report positive correlations between plant size and the size of the various organs produced. These correlations, however, even when significant, are in most cases so small, and there are so many instances where the coefficients are clearly not significant or are even negative, that no general conclusion, supported by the whole body of evidence, can well be drawn.

Materials and Methods

The present paper is the result of a study of a group of 562 bean plants grown during the summer of 1918 as a part of a larger investigation. The beans were Red Kidneys, and although they were not members of a pure line, they were so similar in all characters studied as to indicate that no wide genetic differences existed among

them. Seeds of uniform size were selected and were planted June first. The soil of the plot varied decidedly in fertility, with the result that some of the plants grew luxuriantly, many of them reaching a total dry weight of 150 grams, whereas others were much dwarfed, reaching only 4 or 5 grams at maturity. The bulk of the population were intermediate in size.

Over two hundred of the plants were harvested from time to time during the summer, representatives of all stages from the young seedling to the appearance of flowers being obtained. The rest, 344 in number, grew to maturity and were harvested then. The number of leaves,[2] pods and seeds were counted and dry weight determinations made of the total bulk of the leaves, of the stem system and of the yield of fruit, separate determinations being recorded for total pods (without seeds) and total seeds. From these data, the dry weight of the entire plant, of the vegetative shoot and of the reproductive structures could easily be determined, as well as the average weight of leaf, pod and seed for each plant. Correlations were then made between the average weight of each of these organs, respectively, and the size of the plant. The latter was represented either by the weight of the shoot (stem plus leaves), the weight of the fruit (yield), the number of leaves, the number of pods or the number of seeds.

RESULTS

The coefficients of correlation thus determined are set forth in Table I. Eight of these involve the 344 mature plants studied and one (the first) involves the 218 immature plants. Three of the correlation tables on which these constants are based—those showing the relation between shoot weight and (1) average leaf weight, (2) average pod weight and (3) average seed weight in mature plants—are also presented in Tables II, III and IV.

It will be noted that in every case there is a positive

[2] Very small leaves, less than one third the average size for the plant, were not counted.

TABLE I

CORRELATIONS BETWEEN BODY SIZE AND AVERAGE ORGAN SIZE

Dry weight of shoot: Average dry weight of leaf[5]	$r = + .891 \pm .009$
Dry weight of shoot: Average dry weight of leaf	$r = + .769 \pm .015$
Number of leaves: Average dry weight of leaf	$r = + .607 \pm .023$
Dry weight of shoot: Average dry weight of pod	$r = + .301 \pm .033$
Total weight of fruit: Average dry weight of pod	$r = + .460 \pm .029$
Number of pods: Average dry weight of pods	$r = + .219 \pm .035$
Dry weight of shoot: Average dry weight of seed	$r = + .229 \pm .035$
Total weight of fruit: Average dry weight of seed	$r = + .390 \pm .031$
Number of seeds: Average dry weight of seed	$r = + .180 \pm .035$

correlation between the average weight of the organ studied and the size of the entire plant, however measured. This correlation is in most cases rather small in amount, but in every instance but one the coefficient is more than six times as large as its probable error and may therefore be regarded as significant. The coefficients are least in the case of the seed, somewhat higher for the pod and of considerable magnitude for the leaf, being particularly high in the case of the immature plants. From these figures, therefore, it might reasonably be inferred that there is a significant relation, though a small one, between organ size and size of plant in beans,

TABLE II

CORRELATION BETWEEN DRY WEIGHT OF SHOOT AND AVERAGE DRY WEIGHT OF LEAF

Dry weight of shoot in grams (Class centers)

Average dry weight of leaf in grams (Class centers)	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94
1.25														1										
1.15										1	1								1					
1.05																								
.95									2			1	1		1	1			1					
.85							2	1	4	4	5	8	5	4	3	5	6	1	1		1			1
.75				2		6	3	8	6	6	6	5	5	4	5	3	1							1
.65			1	1	4	7	13	10	5	5	1	5	1	2		1					1			
.55		1	2	4	11	17	9	3	3	1	1	1	2		2			1						
.45		2	8	18	3	1	6		1		1					1								
.35		11	15	3	1																			
.25	3	16	3																					
.15	6	6																						
.05	1																							

$r = + .769 \pm .015$

(For plants below 40 grams in shoot weight, $r = + .842 \pm .013$, for plants above 40 grams, $r = + .129 \pm .067$.)

[5] The group of immature plants only.

TABLE III

CORRELATION BETWEEN DRY WEIGHT OF SHOOT AND AVERAGE DRY WEIGHT OF POD

Dry weight of shoot in grams (Class centers)

Average dry weight of pod in grams (Class centers)	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94
2.75				1																				
2.65																								
2.55						1							1			1								
2.45							1						1											
2.35								1				1		1	2									
2.25	1							1	1		1					1								
2.15					1		1	1	1					1		1								1
2.05			2	1		2	1	2	1			2			1									
1.95				8	7	2	2	1	4	1	1		1	1				2	1					
1.85			1	5	2	6	6	2	1	2	1	3		2		2	3		1					
1.75	1	1	4	3	1	4	5	2	4	4		4	2		1	1	1							
1.65		4	4	3	3	6	5	5	1	4	5	3	6	2	3	2	1							
1.55		4	8	3	3	5	6	3	1	4	3	3	2	1	4	1			1		2			
1.45		5	1		1	2		2	3	1	2	2	1	1		2	2							1
1.35		9	2	3	1	1	4	2	3	1		1		2										
1.25		5	4	1		2	2		1		2	1												
1.15	1	5	3																					
1.05	1																							
.95	2	1																						
.85	2																							
.75	2	1																						
.65		1																						

$r = + .301 \pm .033$

(For plants below 16 grams in shoot weight, $r = + .591 \pm .043$; for plants above 16 grams, $r = + .050 \pm .044$.)

the larger plants producing larger leaves, pods and seeds and *vice versa*. This conclusion agrees with that of most previous workers.

A more intensive study of the correlation tables, however, reveals certain facts which do not harmonize with this conclusion, and which suggest that the whole problem is somewhat too complicated to be solved merely by determining such a series of correlation coefficients as appear in Table I. A study of the curves connecting the means for organ size in the correlation tables from which these constants have been derived shows that regression is far from linear and that the character of the curve is essentially the same in every case. The eight curves for the means of organ size on body size in the mature plants are shown in Fig. 1. In every case it is clear that as we

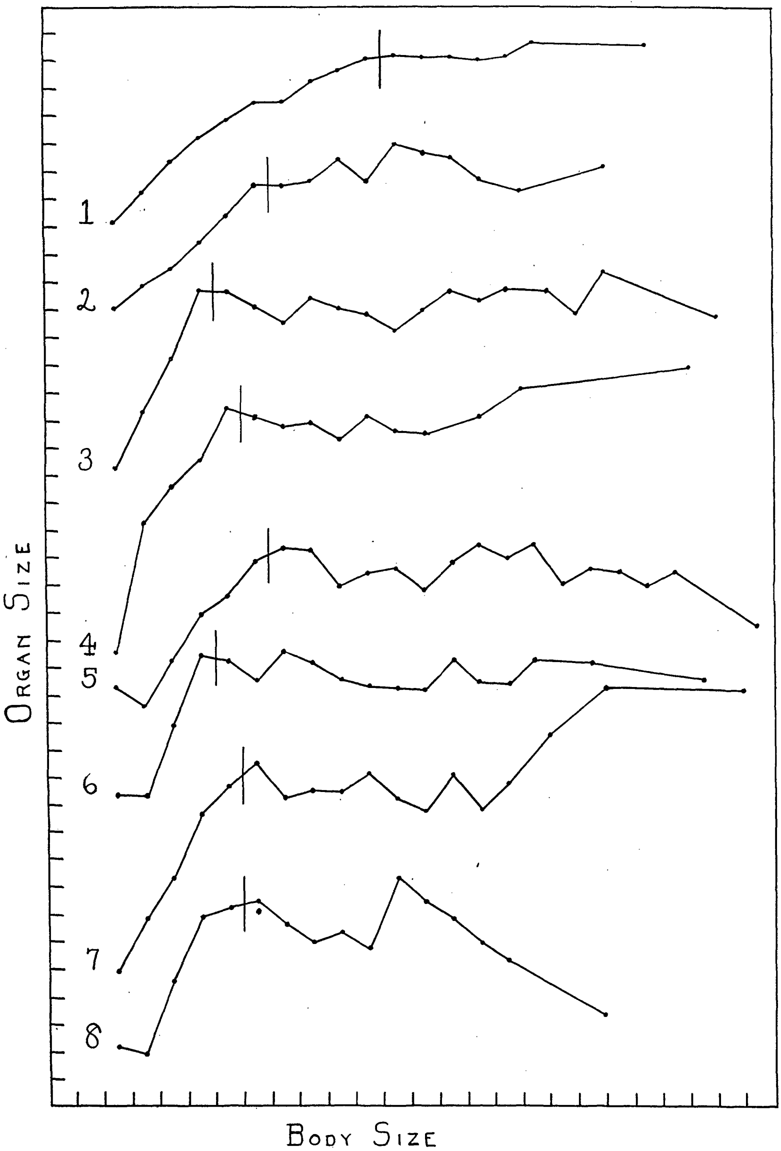

FIG. 1. Curves of the means for organ size on body size in mature plants. (1) Leaf weight on shoot weight; (2) leaf weight on number of leaves per plant; (3) pod weight on shoot weight; (4) pod weight on yield of fruit; (5) pod weight on number of pods per plant; (6) seed weight on shoot weight; (7) seed weight on yield of fruit; seed weight on number of seeds per plant. Vertical lines indicate points where division was made into "large" and "small" plants.

progress from the smaller plants to the larger ones there is *up to a certain point* a marked increase in the average organ size for the plant; but that beyond this point the curve flattens and thence onward an increase in plant size has essentially no effect on the average size of leaf, pod or seed.

TABLE IV

CORRELATION BETWEEN DRY WEIGHT OF SHOOT AND AVERAGE DRY WEIGHT OF SEED

Dry weight of shoot in grams (Class centers)

Average dry weight of seed in grams (Class centers)	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94
.530								1					1			1								
.515							1																	
.500					1						1		1		1									
.485														1										
.470			1			1	2		1			1			1	1								
.455			1	3		1		1	1															
.440					1		2					1		1										
.425						2	1	1		1						1	1	1						
.410			1	5	3	1	4		2	2	1	3		1		1	2	1						
.395	2		2	4	2	5	1	2	3		1	1	1											1
.380			1	7	3	7	8	8	4	3	2	1	3	2	1	1			1		1			
.365	1	1	1	1	1	3	2	3	1	3	3	3	2	1	2	2	1							1
.350		2	7	2	6	3	8	1	2	3	2	3	3	1	3		1		2					
.335		3	2	2		2	1	1	2	4	1	2	1	1	1	1								
.320	1	11	8	3	1	2	2	2	3		3	2	1				1				1			
.305		5	1			1		1					1	1	1		1							
.290	1	4	1	1		1	1	1	1	1		2		1		3								
.275	1	6			1						1			1										
.260	2	1	1			1			1			1			1									
.245	1	1				1																		
.230		1	2																					
.215	1																							
.200																								
.185																								
.170		1																						

$r = +.229 \pm .035$

(For plants below 16 grams in shoot weight, $r = +.555 \pm .046$; for plants above 16 grams, $r = -.030 \pm .043$.)

There is thus evidently a much higher correlation between body size and organ size in small plants than in larger ones, and a single correlation coefficient covering both groups clearly fails to give an accurate picture of the facts. Each of the eight correlations involving the mature plants was therefore divided into two parts, one including the small plants and one the large ones, the line of division coming at approximately the point where

the curve of means stops ascending and begins to flatten out. This point is marked by a vertical line on each of the curves in Fig. 1 and in the same way in Tables II, III and IV. The coefficient of correlation was now determined both for the group below this point and for the group above it—for the small plants and for the large ones. The constants thus derived are shown in Table V. A study of these figures makes it clear that in the smaller plants there is a decided correlation between body size and organ size (always exceeding ten times its probable error), but in the larger plants practically none at all.[3] This emphasizes the conclusion drawn from the character of the curve of means, namely, that up to a certain point increased body size is followed by increased size of organs produced, but that beyond this point there is no relation between the two.

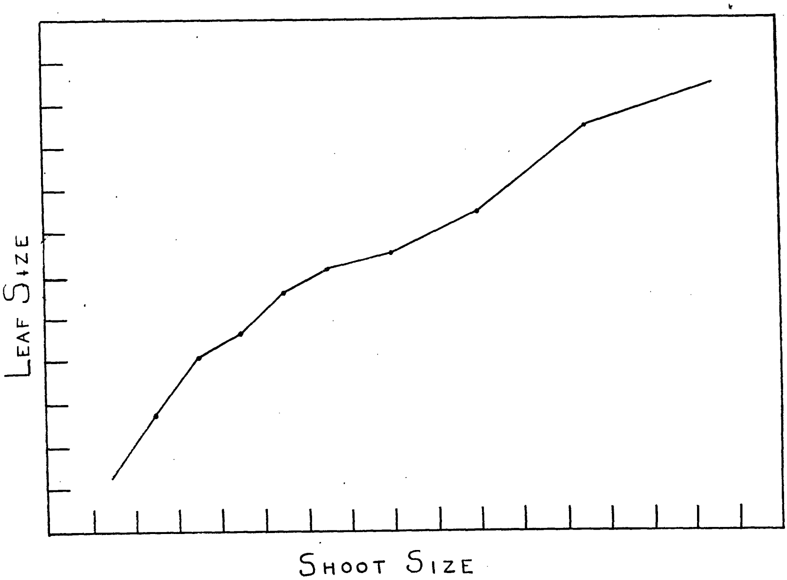

FIG. 2. Curve of means for leaf weight on shoot weight in immature plants.

It is of interest to note that in the case of the immature plants the curve of means for leaf size rises steadily as

[3] It will be noted that very similar results were obtained by Shaw (17) in correlating seed size with vine length in peas.

plant size increases (Fig. 2), showing no sign of the flattening characteristic of the mature plants.

What reason may we assign in the case of the mature plants for this radical difference between large individuals and small ones? And why, in immature plants, should no such difference exist? The suggestion at once comes to mind that there may really be no relation between body size and organ size in any case, but that organ size may be determined, instead, by the size of the particular axial *growing point* from which the organ has

TABLE V

CORRELATIONS BETWEEN BODY SIZE AND AVERAGE ORGAN SIZE IN THE ENTIRE GROUP (OF MATURE PLANTS); IN THE SMALLER PLANTS (THOSE BELOW THE VERTICAL LINE IN FIG. 1); AND IN THE LARGER PLANTS (THOSE ABOVE THE VERTICAL LINE IN FIG. 1).

	Entire Group	Smaller Plants	Larger Plants
Shoot: Average leaf	+.769 ± .015	+.842 ± .013	+.129 ± .067
Number of leaves: Average leaf	+.607 ± .023	+.665 ± .029	+.111 ± .050
Shoot: Average pod	+.301 ± .033	+.591 ± .043	+.050 ± .044
Total fruit: Average pod	+.460 ± .029	+.652 ± .040	+.279 ± .040
Number of pods: Average pod	+.219 ± .035	+.486 ± .048	−.083 ± .045
Shoot: Average seed	+.229 ± .035	+.555 ± .046	−.030 ± .043
Total fruit: Average seed	+.390 ± .031	+.559 ± .047	+.206 ± .041
Number of seeds: Average seed	+.180 ± .035	+.509 ± .045	−.059 ± .045

developed. It is a matter of common observation that in most herbaceous plants the diameter of the newly formed stem internodes (and therefore presumably the diameter of the terminal growing point which gives rise to the primary tissues of the stem) is comparatively small in the seedling, but increases slowly as the plant grows larger until a presumably optimum diameter is attained which is rarely exceeded except in the case of very rank and luxuriant shoots.[4] Further growth of the plant as a whole results in an increase in the length and number of its stems, but in no increase in their primary diameter. Stem diameter is of course not uniform, many lateral

[4] The thickness of these primary tissues of the young stem is of course increased later by secondary growth, with which we are not concerned.

branches and even the main ones under unfavorable conditions, or as vegetative growth slackens, being comparatively small; and we know that organ size also varies considerably in the individual. The point to be emphasized here is that there tends to be a maximum for the primary diameter of the stem which is attained while the plant is still fairly small, and which thereafter is normally not exceeded, no matter how great the total size of the plant body may eventually become. The same rule applies of course to woody plants, the twigs of a large tree being no thicker, other things being equal, than those of a small tree, although both are usually thicker than the early axis of the seedling.

Now if the organs (leaves and fruits) developed by the primary meristem owe the size which they finally attain to the size of the growing point from which they arise; or if, to put it another way, all the structures developed at a given growing point—the stem axis and the lateral organs—are correlated with one another in size, then the biometrical results which we have set forth in our bean plants are readily explicable. The comparatively small plants are, on this supposition, the ones which did not attain at maturity sufficient size to have arrived at the maximum stem (growing point) diameter; and the smaller the plants, the smaller is their stem diameter, down to depauperate individuals whose mature primary axes are no stouter than those of the seedling. In these smaller plants, therefore, the significant correlation which we observed would naturally be expected between organ size (dependent on growing point size) and body size (definitely related to growing point size). In the case of the larger plants, however (those above the point at which the curve of means flattened out), where the maximum stem diameter or growing point size has already been attained and where, therefore, there is no relation between body size and growing point size, it is only natural that there should be (as we observed) no correlation at all. Furthermore, in the group of imma-

ture plants studied, which included everything from seedlings to plants coming into flower, there is naturally a very close relation between body size and growing point size, since these individuals all belong to that portion of the plant's life history where its primary growing points are progressively increasing in diameter, the maximum being attained in beans just before the blooming period. It would be only natural that in this group of plants in which both body size and growing point size are progressively rising, there should be a high correlation between body size and organ size.

This hypothesis of a direct relation between the size of an organ and the size of the growing point from which it arose will evidently explain the facts which we have observed in the case of our bean plants. The problem now remains to discover a means whereby we may determine more directly the soundness of the hypothesis. The size of an organ can be measured fairly accurately either by weighing it or by determining its dimensions and computing its volume. To get a measurement which shall represent at all adequately the size of the growing point, however, is a more difficult matter. The cross-sectional area of the stem axis which is produced from the growing point might be used; but since the terminal growing point is of course a primary meristem entirely and since the early activity of a secondary growing point or cambium often affects almost immediately the diameter of the stem, it is evident that stem cross section, particularly in regions very far removed from the growing point, can not be counted on as an accurate indication of growing point size. We can confine ourselves to a tissue which is entirely primary in its origin, however, and which is not affected by subsequent secondary growth if we measure simply the *pith*. The magnitude of the correlation between organ bulk and cross-sectional area of the pith of the internode below the attachment of the organ might be expected to give us a fairly good idea as to whether organ size and grow-

ing point size are definitely related to one another or not. The organ most readily studied and most clearly significant in such a problem is of course the leaf.

The bean plant is evidently not well suited for such a study, since its pith is rather irregular in outline and not sharply delimited. The twigs and leaves of the rock maple (*Acer saccharum*), however, on which the writer is carrying on some other work, have proven very satisfactory for an investigation of this kind. The pith in this species is approximately circular in cross section and is sharply delimited, and the leaves are of uniform and fairly considerable thickness.

A series of twigs collected during the summer from a single tree were studied. The area of the blade was determined by tracing its outline on standard weight paper, cutting this out and weighing the cut-out. Blade thickness was measured by a micrometer caliper at two points away from the main veins and situated symmetrically on opposite sides of the midrib, the average of the two measurements being taken. The product of area X thickness of course gives us the blade volume. To determine pith area a cross section was cut at the middle of the internode, the pith diameter measured in two directions at right angles to each other by a micrometer stage, the results averaged and the area computed therefrom.

Total blade volume (the sum of the volumes of the two blades borne at a given node) was correlated with the cross-sectional area of the pith of the internode below for over 100 leaf pairs from this tree, taken from all parts of its crown. The results are shown in Table VI. It is quite evident from the size of the correlation coefficient ($+.807 \pm .024$) that there is an unquestionable relationship between leaf size and pith area, the size of the leaf being governed pretty largely by the stoutness of that portion of the twig from which it springs. It would seem, therefore, that the size relationships between the structures laid down by the terminal meristem persist as these structures develop to maturity, these *relative* sizes re-

maining constant regardless of the *actual* size which is attained. The terminal growing point, like the animal embryo, develops as a symmetrical and interrelated whole.

Although the size of the leaf thus seems to be closely dependent upon that of the growing point, the size of the reproductive organs is evidently much less so. We have

TABLE VI

CORRELATION BETWEEN THE BLADE VOLUME (IN CUBIC CENTIMETERS) OF THE TWO LEAVES AT A NODE, IN ACER SACCHARUM, AND THE CROSS SECTIONAL AREA (IN SQUARE MILLIMETERS) OF THE PITH OF THE INTERNODE BELOW.

Blade volume in cubic centimeters (Class centers)

Pith area in square millimeters (Class centers)	.3	.5	.7	.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7
7.05																						1	
6.75																							
6.45																							
6.15																							
5.85																							
5.55																							
5.25																					1		1
4.95																						2	
4.65																1				2	1		
4.35																						1	
4.05													1									1	
3.75													1	1				1					
3.45					1	1								1	2								
3.15									1													1	1
2.85							1					1	1	1	1			1			1		
2.55					1							1		2	1	1							
2.25						1									3	1			1				
1.95							1		3			1											
1.65						2			1		1	3	1	1									
1.35		1		1	1			2		2	2			1									
1.05			2	3		1	5	1	2		1												
.75	1	1		2	2	1	3	3															
.45			2		3	1																	
.15			2																				

$r = + .807 \pm .024$

seen that leaves do not reach their maximum size except in plants with shoots of about forty grams dry weight or more. The maximum pod and seed size, however, is attained in much smaller plants, usually those in the vicinity of sixteen grams. In other words, a reduction in the size of the growing point is felt much more quickly by the leaf than by the fruit. It is only in plants which are really depauperate that the fruit and seed size is reduced

below the normal. The reason for this may lie in the fact that the flower is an independent axis rather than a lateral organ like the leaf and may therefore be less affected by the size of the main axis from which it springs. It is well known that flowers are more constant in size and other characters and less affected by environmental conditions than are vegetative organs.

It should be recognized that in the grasses, where most of the work along this line has been done, conditions are somewhat different from those in dicotyledons such as the bean; since the plant body, or at least each shoot or culm, is essentially determinate in growth, with a limited number of parts. This may sometimes affect the statistical results obtained, but we believe that conditions are fundamentally the same in the two groups. It is of interest to note the conclusions of Leighty and others, for small grains, *viz.*, that the correlations between organ size and plant size are considerably higher in small, poorly developed plants than in large ones,—a situation precisely similar to that which we have reported in beans. The whole problem can perhaps be solved best, however, by studying such an indeterminate type of plant body as is characteristic of the ordinary dicotyledon.

Conclusions

We may conclude, therefore, that the size of the plant body is not the direct causative factor in determining the size of the leaves, fruits or seeds which it produces, as has been suggested or implied by many investigators, but that the size of any given organ depends rather upon the size of the growing point out of which it has been developed. Any factor, be it age, moisture or food supply, which alters the size of the meristem, will thus alter the size of the organs produced by this meristem. There seems to be nothing in these higher plants closely corresponding to the definite organization with which we are familiar in the animal individual, where size of body is definitely related to size of organs.

The present study emphasizes the difficulties lying in the path of the investigator who attempts to solve such a problem as this merely by determining a single series of biometrical constants without taking into account the various morphological and physiological factors which may be involved.

Summary

1. The problem of the relationship between the size of the plant body and the size of the organs it produces has been studied by various workers, who find that in most cases there is a small but significant correlation between these characters.

2. In a series of bean plants, the coefficients of correlation were determined between plant size, as measured by dry weight of shoot, dry weight of fruit, number of leaves, number of pods and number of seeds; and the average dry weight per plant of leaf, pod and seed. A positive and significant correlation, though usually a small one, was found in each case.

3. An examination of the curve of means for organ size on plant size shows that in each case the curve rises steeply at first and then flattens out. In other words, an increase in the size of the plant is accompanied by an increase in the size of its organs if we consider comparatively small plants only; but after a certain size is reached, any further increase in plant size is not followed by increase in organ size. Separate correlations between plant size and organ size made for small plants (those below the point where the curve flattens) and for large ones (those above it) showed a very decided correlation in the former and practically none at all in the latter.

4. These facts suggested that the size of an organ may not be correlated with body size at all, but rather with the size of the axial growing point from which it develops. In support of this idea attention is called to the fact that during the early stages of a plant's growth there is

up to a certain point a progressive and parallel increase in the size of the plant and in the size of the primary meristems of its axes; but that after this point is reached meristem size remains constant and further increase in body size is not accompanied by any increase at all in that of the growing point.

5. Favorable material to test this hypothesis directly was afforded by twigs and leaves of *Acer saccharum*. The correlation between the blade volume of a given leaf pair and the cross-sectional area of the pith of the internode below (used as an index to the size of the growing point from which the leaves had developed) was found to be high ($+.807 \pm .024$).

6. It is therefore concluded that the size of a plant organ (leaf, fruit or seed) is dependent not upon the body size of the plant on which it is borne, but rather upon the size of the growing point from which it developed.

BIBLIOGRAPHY

1. Arny, A. C., and R. J. Garber. Variation and Correlation in Wheat, with Special Reference to Weight of Seed Planted. *Jour. Agric. Research*, 14: 359–392, 1918.
2. Ewing, E. C. Correlation of Characters in Corn. *Cornell Exp. Sta. Bull.*, 287: 67–100, 1910.
3. Harris, J. Arthur. On the Correlation between Somatic Characters and Fertility. II. Illustrations from *Phaseolus vulgaris*. *Amer. Jour. Bot.*, 1: 398–411, 1914.
4. ——— A Quantitative Study of the Factors Influencing the Weight of the Bean Seed. II. Correlation between Number of Pods per Plant and Seed Weight. *Bull. Torrey Bot. Club*, 43: 485–494, 1916.
5. Hayes, H. K. Correlation and Inheritance in *Nicotiana tabacum*. *Conn. Exp. Sta. Bull.* (New Haven), 171: 3–45, 1912.
6. Hutcheson, T. B., and T. K. Wolfe. Relation between Yield and Ear Characters in Corn. *Jour. Amer. Soc. Agron.*, 10: 250–255, 1918.
7. Leighty, C. E. Correlation of Characters in Oats, with Special Reference to Breeding. Amer. Breeders Assoc. Rept., 7: 50–61, 1911.
8. ———. Variation and Correlation of Oats. II. Effect of Differences in Environment, Variety and Methods on Biometrical Constants. *Cornell Exp. Sta. Mem.*, 4, 1914.
9. Love, H. H. A Study of the Large and Small Grain Question. Amer. Breeders Assoc. Rept., 7: 109–118, 1911.
10. Love, H. H., and C. E. Leighty. Variation and Correlation of Oats. I. Studies Showing the Effect of Seasonal Changes on Biometrical Constants. *Cornell Exp. Sta. Mem.*, 3, 1914.

11. Lyon, T. L. Some Correlated Characters in Wheat and their Transmission. Amer. Breeders Assoc. Rept., 2: 29–39, 1906.
12. Myers, C. H. Effect of Fertility upon Variation and Correlation in Wheat. Amer. Breeders Assoc. Rept., 7: 61–74, 1911.
13. Olson, P. J., C. P. Bull and H. K. Hayes. Ear Type Selection and Yield in Corn. *Minnesota Exp. Sta. Bull.*, 174, 1918.
14. Roberts, H. F. Variation and Correlation in Wheat. Amer. Breeders Assoc. Rept., 7: 80–109, 1911.
15. Shaw, J. K. Variation in Apples. Mass. Exp. Sta. Rept., 1910: 194–213.
16. ——— Climatic Adaptations of Apple Varieties. Mass. Exp. Sta. Rept., 1911: 177–245.
17. ——— Heredity, Correlation and Variation in Garden Peas. Mass. Exp. Sta. Rept., 1912: 82–101.
18. ——— A Study of Variation in Apples. *Mass. Sta. Bull.*, 149: 21–36, 1914.
19. Stewart, J. P. Factors Influencing Yield, Color, Size and Growth in Apples. Penn. Sta. Rept., 1911: 401–511.
20. Waldron, L. R. A Suggestion Regarding Light and Heavy Grain. AMER. NAT., 44: 48–56, 1910.